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- (54) Title: OPTICAL COMMUNICATION SYSTEMS, APPARATUSES, AND METHODS  
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## (57) Abstract

Optical communication systems, apparatuses and methods are disclosed. Optical systems of the present invention include an optical transmitter (12), an optical receiver (14), and an optical processing node (22) optically connecting the transmitter and the receiver. The optical processing node includes at least one waveband selector (30) configured to selectively pass at least one optical waveband of information including a plurality of information carrying wavelengths from the transmitter to the receiver. In an embodiment, the optical processing node includes a switch (22) configured to separate an optical signal into optical wavebands of information and selectively pass the optical wavebands to the receiver without separating the plurality of information carrying wavelengths into individual wavelengths. In an embodiment of the optical transmission system, a plurality of nodes containing optical transmitters, receivers, and/or switching equipment are interconnected using optical processing nodes to form the network. The assignment of wavelengths to information and to destination can be performed at the client system interface with the optical network to provide for wavelength and waveband management without wavelength conversion.

## (57) Abrégé

L'invention concerne des procédés, des appareils et des systèmes de communication optiques. Les systèmes optiques de l'invention comportent un émetteur optique (12), un récepteur optique (14) et un noeud de traitement optique (22) connectant optiquement l'émetteur et le récepteur. Le noeud de traitement optique comporte au moins un sélecteur de gammes d'ondes (30) configuré pour faire passer sélectivement au moins un gamme d'ondes optiques d'information contenant plusieurs longueurs d'onde porteuses d'information, de l'émetteur au récepteur. Dans un mode de réalisation, le noeud de traitement optique comprend un commutateur (22) configuré pour séparer un signal optique en gammes d'ondes optiques d'information et faire passer sélectivement les gammes d'ondes optiques au récepteur sans séparer en longueurs d'onde séparées les longueurs d'ondes porteuses. Dans un mode de réalisation du système de transmission optique, plusieurs noeuds contenant des récepteurs, des émetteurs optiques et/ou un équipement de commutation, sont connectés entre eux au moyen de noeuds de traitement optiques de sorte que le réseau soit formé. L'attribution de longueurs d'onde aux informations et à la destination peut être assurée au niveau de l'interface système client avec le réseau optique de manière que la gestion de la gamme d'ondes et de la longueur d'onde soit assurée sans conversion de longueur d'onde.

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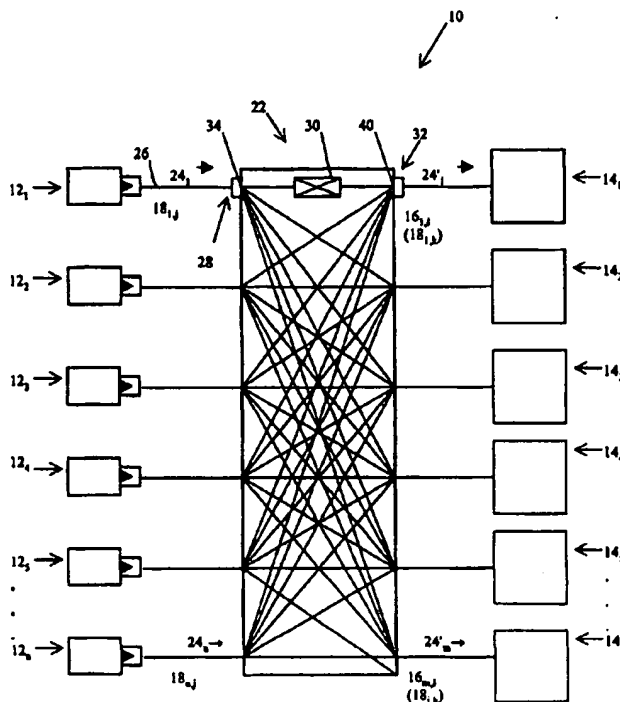
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Optical communication systems, apparatuses and methods are disclosed. Optical systems of the present invention include an optical transmitter (12), an optical receiver (14), and an optical processing node (22) optically connecting the transmitter and the receiver. The optical processing node includes at least one waveband selector (30) configured to selectively pass at least one optical waveband of information including a plurality of information carrying wavelengths from the transmitter to the receiver. In an embodiment, the optical processing node includes a switch (22) configured to separate an optical signal into optical wavebands of information and selectively pass the optical wavebands to the receiver without separating the plurality of information carrying wavelengths into individual wavelengths. In an embodiment of the optical transmission system, a plurality of nodes containing optical transmitters, receivers, and/or switching equipment are interconnected using optical processing nodes to form the network. The assignment of wavelengths to information and to destination can be performed at the client system interface with the optical network to provide for wavelength and waveband management without wavelength conversion.



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Description

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## OPTICAL COMMUNICATION SYSTEMS, APPARATUSES, AND METHODS

## FIELD OF THE INVENTION

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The present invention is directed generally to network, transmission and communication systems. More particularly, the invention relates to optical information network, transmission and communication systems and optical components, such as cross connect switches, add/drop devices, demultiplexers, and multiplexers, for use therein.

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## BACKGROUND OF THE INVENTION

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10 The development of digital technology has provided electronic access to a vast amount of information. The increased access to information has fueled an increasing desire to quickly obtain and process the information. This desire has, in turn, placed ever increasing demands for faster and higher capacity electronic information processing equipment (computers) and transmission networks and systems linking the processing equipment (i.e., telephone lines, cable television (CATV) systems, local, wide and metropolitan area networks (LAN, WAN, and MAN)).

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20 In response to these demands, many transmission systems in use today either have been or will be converted from electrical to optical networks. Optical transmission systems provide substantially larger information transmission bandwidths than electrical systems, which provides for increased information transmission capacities.

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25 Early optical transmission systems were developed as space division multiplex (SDM) systems. In early SDM systems, one signal was transmitted as a single optical wavelength in each waveguide, i.e., fiber optic strand. A number of waveguides were clustered to form a fiber optic cable that provided for the transmission of a plurality of signals in spaced relationship.

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5 As transmission capacity demands increased, optical  
transmission and receiving equipment was developed that  
provided for time division multiplexed (TDM) transmission of  
10 a plurality of distinct optical signals in a single  
5 waveguide. Optical TDM systems are generally analogous to  
electrical TDM systems in that the signals are transmitted on  
a common line, but spaced in time. The transmission of the  
15 signals is in a known sequence allows the plurality of  
distinct signals to be separated after transmission.

10 A problem with TDM transmission is the transmission  
bandwidth in the waveguide increases with each additional  
20 multiplexed signal. For example, information can be  
transmitted through a waveguide via a first series of optical  
signals separated in time by an interval  $\Delta t$ . Additional  
25 information can also be transmitted over the same waveguide  
using a second series of optical signals during the time  
interval  $\Delta t$  by merely offsetting the transmission of the  
first and second series of signals in time. While an optical  
30 signal in each series is only transmitted through the  
20 waveguide every  $\Delta t$  interval, two signals, or  $n$  signals in the  
general case, are passing through the waveguide during each  
interval. Therefore, the overall transmission rate in TDM  
35 systems increases directly with the number of signals  
transmitted.

25 Signal transmission rates in fiber optic waveguides are  
generally limited by the interactions between the optical  
40 signal (i.e., light pulse) and microstructural features of  
the waveguide material. As the transmission rate is  
increased, signal dispersion in the fiber and other  
45 transmission effects deleterious to signal quality begin to  
30 occur as a result of the interactions.

Optical signals are typically transmitted in wavelengths  
that minimize dispersion in the fiber. For example, older  
50 optical systems are commonly operated around 1310 nm and

5 employ SMF-28 fiber manufactured by Corning, or its  
equivalent, which has minimum dispersion at or near 1310 nm.  
10 Another type of fiber, known as dispersion shifted fiber, has  
its minimum dispersion at or near 1550 nm. A third type of  
5 fiber sold by Corning as LS fiber and by Lucent Technology as  
TrueWave has its minimum dispersion at or near 1550 nm. In  
addition to having different minimum dispersion wavelengths,  
15 each fiber has varying immunity to other signal degradation  
mechanisms, such as four wave mixing, at increased  
20 transmission rates.

The transmission rates at which the signal quality  
20 begins to degrade are substantially lower ( $< 40$  Gbps) than  
the capacity of the transmission and receiving equipment.  
Therefore, TDM systems, which increase capacity by increasing  
25 transmission rates, generally have only a limited potential  
for further increasing the capacity of optical transmission  
systems.

The development of wavelength division multiplex (WDM)  
30 transmission systems has provided a way to increase the  
capacity of optical systems without encountering the  
20 waveguide limitations present in TDM systems. In a WDM  
system, a plurality of optical signals including information  
35 carrying wavelengths are combined to produce a multiple  
wavelength signal that is transmitted through the system to a  
25 receiver. After the multiple wavelength signal is received,  
the information carrying wavelengths are separated from the  
40 multiple wavelength signal and provided to a corresponding  
plurality of destinations. Unlike TDM systems, only one WDM  
signal is transmitted during a time interval  $\Delta t$ , although  
45 30 each WDM signal contains a plurality of signals including  
information carrying wavelengths.

Also unlike TDM systems, the waveguide material does not  
50 realistically limit the information bandwidth that can be  
placed on a single optical fiber in a WDM system. One

5 skilled in the art can also appreciate that the number of  
wavelengths that can be used to transmit information over a  
single waveguide is currently limited by the complexity of  
10 the transmission and receiving equipment required to  
5 generate, transmit, receive, and separate the multiple  
wavelength signal.

15 Currently, many optical transmission systems must  
convert the optical signal to an electrical signal during  
transmission to perform transmission functions, such as  
10 signal amplification and switching. The optical to  
electrical conversion, and vice versa, substantially limits  
20 the overall transmission speed of the network, and increases  
transmission losses in the network. Thus, it has been an  
industry goal to develop optical amplifiers and optical  
15 cross-connect switches to provide for high speed, all optical  
transmission systems.

The development of optical fiber amplifiers produced by  
doping the optical fiber with Erbium ions ( $\text{Er}^{3+}$ ) or other  
30 elements has allowed for the elimination of electrical  
amplifiers and the requisite time delay and costs associated  
20 with signal conversion. In addition to simplifying and  
decreasing the cost of the equipment required to amplify a  
35 signal, optical fiber amplifiers have proven effective for  
amplifying a plurality of wavelengths without a commensurate  
25 increase in the complexity of the amplifier as additional  
wavelengths are included in the WDM signal.

40 Unlike optical amplifiers, optical cross-connect  
switches greatly increase in complexity as the number of  
waveguides entering and exiting the switch and the number of  
45 wavelengths per waveguide increases. As a result, the  
expansion of all optical systems has been somewhat inhibited  
by the lack of simple, efficient, and economically attractive  
optical cross-connect switching systems.



5 A number of optical cross-connect switches are based on  
one or more 1x2 signal splitters or 2x2 signal couplers used  
in conjunction with one or more wavelength filters, such as  
10 described in U.S. Patent No. 5,446,809 issued to Fritz et al.  
5 The complexity of these types of switch increases not only  
with the number of inputs and outputs in the switch, but also  
with the number of wavelengths being switched. For example,  
15 if a 2x2 switch is provided to switch two eight wavelength  
WDM input signals to two output signals, the switch would  
10 have to include 32 gratings to allow all wavelengths to be  
switched. However, if a 4x4 switch is provided to switch  
20 four sixteen wavelength WDM input signals to four output  
signals, 256 gratings will be required. In addition, the  
flexibility of the switch is limited because additional  
25 gratings or filters must be added to each waveguide  
connecting each input to each output of the switch for every  
wavelength that is to be switched.

Another complication is that different signals entering  
30 a switch at different input ports will often times be carried  
20 by the same wavelengths. The use of common wavelengths  
frequently occurs because optical signals are generally  
transmitted using a relatively narrow range of wavelengths  
35 that have been established by optical standards committees  
with the goal of minimizing transmission losses in a  
25 waveguide and allowing equipment standardization in the  
industry.

40 If two signals on a common wavelength from different  
inputs are switched to the same waveguide, both signals will  
be destroyed. The switch, therefore, must be designed to  
45 30 prevent the inadvertent destruction of signals transmitted to  
the switch on a common wavelength.

Switches can be provided that "block" the switching of  
certain wavelengths to prevent destruction of two signals on  
50 a common wavelength. Switches can also be provided with

5 wavelength converters that are used to change the wavelength  
of a signal, in lieu of blocking the signal, to prevent the  
destruction of the signal. U.S. Patent No. 5,627,925 issued  
10 to Alferness et al. discloses an example of a switch that  
5 includes wavelength converters to provide a nonblocking  
switch. As expected, the use of wavelength converters adds a  
further degree of complexity to the design and function of  
15 optical cross-connect switches.

An alternative to adding wavelength converters to  
10 provide a nonblocking switch is to limit the wavelengths used  
in the system. For example, U.S. Patent No. 4,821,255 issued  
20 to Kobrinski discloses an optical system employing  
transmission systems that transmit data at a different  
wavelength to each destination receiving system, i.e., N  
25 wavelengths for N receiving systems. In this manner, the  
optical system does not require a nonblocking switch and the  
assignment of a specific wavelength to each receiving system  
allows for a passive optical connection ("hard wire") between  
30 a transmission demultiplexer and a receiving multiplexer.

20 In addition, the same N wavelengths can be transmitted  
by each transmitting system if the receiving system is  
coordinated to receive a different wavelength from each  
35 transmitting system. Wavelength coordination eliminates the  
need for wavelength converters and allows the same  
25 transmitters and receivers to be used in the system.

40 A difficulty with passive switching systems is that the  
streamlined nature renders the switch somewhat inflexible.  
For example, a specified wavelength is used to transmit  
signals between a transmission system and a receiving system.  
45 Therefore, it may be difficult to transmit multiple signals  
from one transmitting system to one receiving system at any  
one time. It is presumably possible to assign additional  
wavelengths to each of N transmitter/receiver combinations;  
50

5           however, for each wavelength added to each system, either  $N^2$   
hard wire connections must be made.

10           The problem of signal blockage can also be addressed by  
designing a system having excess transmission capacity. This  
5       would provide more available wavelengths than is required to  
meet current transmission requirements. However, in view of  
the continued expansion of communication networks the excess  
15       capacity may only be short term; therefore the ability to  
upgrade a system remains a desired feature of a switch.

20           Similarly, other optical components, such as add/drop  
devices, demultiplexers and multiplexers, used in optical  
processing nodes between the transmitter and receivers  
increase in complexity and cost as additional channels are  
added to the system. In addition, these components most  
15       likely have to be replaced when a system is reconfigured or  
additional channels are to be added to the system.

25           The continued advancement and development of  
communication systems is limited, at least in part, by the  
constraints placed upon optical systems by the current  
30       technology involved in optical processing systems. The  
elimination or reduction of these constraints is a primary  
concern of industry as the pace of communications continues  
35       to accelerate.

40           Accordingly, there is a need for optical systems and  
optical components that allow for increased network capacity  
25       and flexibility. One aspect of which is to reduce the  
complexity of the equipment and increase the efficiency of  
the transmission system.

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## BRIEF SUMMARY OF THE INVENTION

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The apparatuses and methods of the present invention address the above needs and concerns for improved optical switches and systems. An optical transmission system of the present invention includes one or more optical signal transmitters and optical signal receivers optically communicating via one or more intermediate optical processing nodes. Each optical transmitter includes one or more optical sources, such as modulated lasers, and is configured to transmit information via one or more information carrying wavelengths. Each optical receiver is configured to receive one or more of the information carrying wavelengths using one or more various detection techniques, such as direct detection using optical wavelength filters and photodiodes, or indirect detection using coherent detectors.

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The intermediate optical processing nodes include optical switches, add and/or drop devices including at least one waveband selector configured to pass and substantially prevent the passage of optical wavebands that include a plurality of information carrying wavelengths from the transmitter to the receiver. The optical processing nodes provide for information management and processing in wavebands, instead of separating individual information carrying wavelengths from the signal and individually processing each wavelength. In this manner, high capacity processing of the information can be achieved without the prior complexities involved with increasing capacity. The processing of pluralities of individual wavelengths further provides for accommodating varying numbers and distributions of individual information carrying wavelengths in the system without having to reconfigure or replace system components.

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In an embodiment of the present invention, the optical processing node includes a switch providing cross connections between a plurality of transmitters and receivers. Optical

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5 signals including one or more information carrying  
wavelengths are transmitted to optical switch input ports and  
are distributed to optical switch output ports by splitting  
10 and/or waveband demultiplexing the optical signals depending  
5 upon the type of waveband selector used in the switch.

Waveband selectors include at least one switch, gate, or  
filter, such as an erbium or mechanical switch, a Bragg  
15 grating, or a Mach-Zehnder or Fabry-Perot filter. The  
waveband selectors are generally configured to pass one or  
10 more optical wavebands from the input port to the output port  
in one mode and/or to substantially prevent the passage the  
20 optical wavebands in another mode. A signal is generally  
considered to be substantially prevented from passage, if the  
signal is sufficiently attenuated such that a remnant of the  
25 attenuated signal passing through the waveband selector does  
not destroy signals that have been selectively passed through  
the optical processing node. For example, a 40 dB  
attenuation of a signal will generally be sufficient to  
30 prevent cross-talk interference between remnant signals and  
20 signals passing through the optical processing node.

In an embodiment, each input signal is waveband  
demultiplexed to separate the input signal into waveband  
35 signals. Each waveband signal is then split and each split  
waveband signal passed through a switch to a respective  
25 output port. In an embodiment, an erbium doped fiber is used  
as the switch in the waveband selector to pass, as well as to  
40 controllably amplify or attenuate, the split waveband signal  
to the output port when supplied with optical pump power. In  
the absence of pump power, the erbium fiber absorbs the  
45 30 waveband signal, which substantially prevents the passage of  
the signal. One or more optical combiners are provided at  
the output ports to combine split waveband signal from the  
waveband selector passing optical wavebands from the input  
50 ports.

5 The optical signal at each input port can also be demultiplexed according to a known destination of each waveband signal and the waveband signal is passed to the  
10 output port corresponding to the destination. The optical signals can be transmitted to the switch in wavelengths that  
5 are unique to the signal destination to avoid the use of wavelength converters in the optical system.

15 Bragg gratings, either reflective or transmissive, can be included in the waveband selector to switch any number of  
20 wavebands. The Bragg gratings of the present invention include one grating produced to reflect an entire waveband or  
a series of gratings operated in concert that piecewise correspond to the waveband. In an embodiment, tunable  
25 permanent Bragg gratings can be provided corresponding to each of the wavebands to allow for dynamic reconfiguration of  
the switch.

In addition, the optical processing node can include  
30 transient gratings to provide for additional reconfiguration of the processing node. Transient grating can be formed in  
20 the waveguide either by induction using a coupled circuit or via a writing circuit integrated with the transmission fiber.

35 In an embodiment of the optical transmission system, pluralities of nodes are interconnected to form a network. The nodes may contain optical transmitters, receivers, add  
25 and/or drop devices/ports, and/or switching equipment depending upon whether the node is an origination and/or a  
40 destination node, and whether it is a terminal or an intermediate node. In an embodiment, the network management system is provisioned to assign wavelengths to information  
45 that can be transmitted to destination nodes in a manner to obviate the need for wavelength conversion at the optical switch. Wavelength assignment can be static or dynamically  
50 performed via a network management system, for example, at the client system interface with the optical network. The

5 optical switches cross connecting the nodes and add and/or  
drop ports are configured to respectively switch and add/drop  
10 the information carrying wavelengths in wavebands without  
separately switching the individual wavelengths.

5 Accordingly, the present invention addresses the  
aforementioned problems and provides apparatuses and methods  
to increase the efficiency and capacity of optical  
15 communication systems. These advantages and others will  
become apparent from the following detailed description.

#### 10 BRIEF DESCRIPTION OF THE DRAWINGS

20 Embodiments of the present invention will now be  
described, by way of example only, with reference to the  
accompanying Figures wherein like members bear like reference  
numerals and wherein:

25 Figs. 1-4 depict optical communication systems of the  
present invention;

30 Figs. 5-8b depicts waveband selectors of the present  
invention;

20 Figs. 9-11 depict transient grating waveband selectors  
of the present invention; and,

35 Figs. 12-13 depict multi-node optical communication  
networks of the present invention.

#### DETAILED DESCRIPTION OF THE INVENTION

40 The operation of optical systems 10 of the present  
25 invention will be described generally with reference to the  
drawings for the purpose of illustrating embodiments only and  
not for purposes of limiting the same.

45 Generally, the optical system 10 includes at least one  
optical transmitter 12 and at least one optical receiver 14,  
30 as shown in Fig. 1. Each transmitter 12 is configured to  
transmit information via one or more information carrying  
wavelengths 18<sub>1,k</sub> contained in at least one waveband 16<sub>1,i</sub> to  
50 the receivers 14. Each receiver 14 is configured to receive

5 the information carried via one or more of the information  
carrying wavelengths 18<sub>i,k</sub>. As used herein, the term  
"information" should be broadly construed to include any type  
10 of data, instructions, or signals that can be optically  
5 transmitted.

As shown in Fig. 1, the system 10 further includes at  
least one intermediate optical processing node 20, such as an  
15 optical switch 22. The transmitter 12 is configured to  
transmit an optical signal 24 containing one or more  
10 information carrying wavelengths 18<sub>j</sub> along signal  
transmission waveguide, i.e., fiber, 26 to the switch 22 via  
input port 28. The optical processing node 20 includes one  
20 or more waveband selectors, or selective element, 30 that are  
configured to pass and/or substantially prevent the passage  
of information in wavebands 16<sub>i</sub> to the receiver 14 via output  
25 ports 32. Because the information is being manipulated in  
wavebands, the individual information carrying wavelengths  
18<sub>j</sub> within the waveband 16<sub>i</sub> do not have to be separated in  
individual wavelengths to be managed and processed. Also,  
30 the individual wavelengths 18<sub>j</sub> within the waveband 16<sub>i</sub> be  
varied in the system 10 without affecting the configuration  
of the optical processing node 20. Wavelengths 18<sub>j</sub> in the  
original signal 24 but not within the waveband 16<sub>i</sub> are  
35 prevented from passing through to the receivers 14.

25 In the present invention, optical signals 24 can be  
produced including a number of wavebands 16, each of which may  
40 contain one or more information carrying wavelengths in a  
continuous band of wavelengths or a plurality of wavelength  
bands. For example, a waveband 16 can be defined as having a  
45 continuous range of ~200 GHz containing 20 different  
information carrying wavelengths 18<sub>1-20</sub> spaced apart on a 10  
GHz grid. The bandwidth of each waveband can be uniformly or  
variably sized depending upon the network capacity  
50 requirements. Likewise, the bandwidth of the waveband is not



5 restricted, but can be varied to accommodate varying numbers of wavelengths.

10 Generally, systems 10 of the present invention are configured so that the optical processing nodes do not  
5 separate and process individual information carrying wavelengths during transmission from the transmitter to the receiver. Instead, optical processing nodes 20 are  
15 configured to process the information in wavebands that may include any number of individual information carrying  
10 wavelengths. The processing of information in wavebands decreases the complexity involved in processing large numbers  
20 of channels, while increasing the flexibility of optical components deployed in the transmission path between transmitters and receivers. The bandwidth and number of  
25 information carrying wavelengths within a waveband in a network can be statically or dynamically allocated depending upon the information traffic flow in a given network segment.

Fig. 2 shows a more general arrangement of the system  
30 10, which includes a plurality of transmitter 12<sub>n</sub> optically connected via the switch 22 to a plurality of receiver 14<sub>n</sub>. Analogous to Fig. 1, each transmitter 12<sub>n</sub> transmits an  
20 optical signal 24<sub>n</sub> which includes one or more wavelengths 18<sub>n,j</sub> through a waveguide 26<sub>n</sub> to an input port 28<sub>n</sub> of the switch 22. It will be appreciated that each transmitter may  
35 include one or more sources to transmit and one or more wavelength signals. Likewise, each receiver may include one  
25 or more detectors for receiving the signals.

40 An optical distributor 34<sub>n</sub>, such as a demultiplexer 36 and/or a splitter 38, is provided in the input port 28<sub>n</sub> to  
45 30 distribute the signal 24<sub>n</sub> to the waveband selectors 30<sub>n,i</sub>. An optical combiner 40<sub>n</sub>, such as a wavelength division multiplexer 42 or a coupler 44, is generally included to  
50 combine the wavelengths 18<sub>n,k</sub> in waveband 16<sub>n,i</sub> emerging from the waveband selectors 30<sub>n,m</sub> and provide a modified signal

5           24'<sub>m</sub>. The modified signal 24'<sub>m</sub> exits the switch through the  
output port 32<sub>m</sub> and passes along waveguide 26 to the receiver  
14<sub>m</sub>.

10           For convenience and clarity, Fig. 2 shows only a  
5 waveband selector 30 connecting input port 28<sub>i</sub> to output port  
32<sub>i</sub>. However, it should be understood that the switch 22  
will generally include at least one waveband selector 30  
15 between each input port 28 and each output port 32. It is  
also noted that in some networks it is not necessary that  
10 corresponding input and output ports, e.g. 28<sub>i</sub> and 32<sub>i</sub>, be  
connected to loop a signal back to its point of transmission.  
20 In addition, reference numeral subscripts are generally not  
used in the remainder of the description to simplify the  
nomenclature.

25           Transmitters 12 used in the system 10 can include one or  
more optical emitters and sources that provide continuous  
wave and/or pulsed beams, such as one or more modulated  
lasers as is known in the art. The transmitter 12 may also  
30 include narrow band incoherent sources such as described in  
20 U.S. Patent Nos. 5,191,586 and 5,268,910 issued to Huber or  
other optical sources for producing optical signals.  
Information can be directly or indirectly, e.g., externally,  
35 modulated, or alternatively upconverted, onto an optical  
wavelength, and the information itself may be a time division  
25 multiplexed signal.

40           The transmitter 12 can also be used to provide multiple  
information carrying wavelengths using techniques such as  
described in U.S. Patent No. 5,400,166. Multiple information  
carrying wavelengths can be placed on a single carrier from  
45 30 the transmitter 12 using techniques, such as subcarrier  
modulation (SCM). SCM techniques are described in U.S.  
Patent Nos. 5,101,450, 5,134,509, and 5,301,058 issued to  
Olshansky, 4,989,200 issued to Olshansky et al., 5,432,632  
50 issued to Watanabe and 5,596,436 issued to Sargis et al.

5 The transmitters 12 may be coupled to an external  
electrical network or part of an optical-electrical-optical  
(O/E/O) signal regenerator within an optical network. One  
10 skilled in the art will appreciate that the selection of the  
5 transmitter 12 and the number of information carrying  
wavelengths will depend upon the desired information transfer  
rates for a particular transmitter/receiver system at the  
15 respective nodes. While the present invention provides the  
ability to substantially upgrade the transfer rate for the  
10 node, it does not require that older, slower nodes be upgraded  
upon implementation of the present invention.

20 Consistent with the discussion regarding the transmitter  
12, the receiver 14 and transmission fiber 26 does not have to  
be upgraded to be compatible with the present invention. In  
25 the present invention, the capabilities of the receiving  
system can be taken in account when establishing wavebands to  
be transmitted to a particular receiver 14.

30 As shown in Fig. 3, the receiver 14 will generally be  
used to separate the individual information carrying  
20 wavelengths 18<sub>i,k</sub> in each waveband 16<sub>i</sub> contained in the  
modified signal 24' and convert the information to one or more  
electrical signals. The receiver may include a number of a  
35 wavelength filters, such as Bragg gratings or demultiplexers,  
in combination with an optical to electrical converter (O/E),  
25 such as a photodiode, to provide for direct detection of the  
individual wavelengths. The receiver 14 may also provide for  
40 indirect detection of the individual wavelengths, such as by  
using coherent detector arrangements.

Referring to Fig. 4, the system 10 may include other  
45 types of intermediate processing nodes 20, such as add and/or  
drop devices. The other intermediate processing nodes can be  
employed to selectively modify the wavebands in the signal 24'  
and pass a further modified signal 24" to successive switches  
50 22 and to the receivers 14. The subsequent switches 22

5 between other intermediate processing nodes 20 and the  
receivers 14 can be used to further process the signal 24" to  
produce a further modified signal 24"" which may include  
10 waveband subset 16<sub>11</sub>. The optical add and/or drop  
5 devices/ports can be embodied as a 2x2 switch that can provide  
for 100% programmable add/drop capability or by employing  
directional devices, such as couplers and/or circulators, with  
15 or without waveband selectors 30 to provide varying degrees of  
programmability, as will be further discussed.

10 The receiver 14 can also be used to further distribute  
the signal 24"" as a part of an O/E/O signal regenerator. One  
20 skilled in the art will appreciate that in an O/E/O  
regenerator the optical wavelengths received by the receiver  
14 do not necessarily have to correspond to the optical  
25 wavelengths at which the information is further transmitted.

Waveband selectors 30 generally include at least one  
filter, gate, and/or switch configured to pass and/or  
substantially prevent the passage of at least one waveband 16  
30 received from the inlet port 28 to the outlet port 32. A  
20 signal is generally considered to be substantially prevented  
from passage, if the signal is sufficiently attenuated such  
that a remnant of the attenuated signal that passes through  
35 the waveband selector does not destroy signals that have been  
selectively passed through the optical processing node 20.  
25 For example, a 40 dB attenuation of a signal will generally  
be sufficient to prevent cross-talk interference between  
40 remnant signals and signals being selectively passed through  
the optical processing node 20.

In an embodiment shown in Fig. 5, the switch 22 includes  
45 30 a waveband demultiplexer 36 and an optical signal splitter 38  
coupled via a doped optical fiber 46 to the multiplexer 42 at  
the output port 32. When an optical signal is to be passed to  
the output port 32, the doped fiber is supplied with energy  
50 from the switch pump 48 to overcome the absorption of the

5 doped fiber 46. The amount of energy supplied by the pump 48  
can be controlled to selectively amplify or attenuate a signal  
being passed through the waveband selector 30. In the absence  
10 of optical pump energy, the doped fiber 46 will absorb the  
5 optical signal, thereby substantially preventing the passage  
of that portion of the signal to the outlet port 32. In the  
embodiment of Fig. 5, the wavebands can be switched to any  
15 number of output ports including one to one switching and one  
to many broadcasting.

10 The dopant in the doped optical fiber 46 can be erbium or  
any other dopant including other rare earth elements that can  
20 render the fiber transmissive in one state and substantially  
less transmissive in another state. The selection of a dopant  
in the doped fiber will depend upon the information carrying  
25 wavelengths that are to be switched in the system. Also,  
mechanical, electro-optic, liquid crystal, semiconductor, and  
other types of switches along with gratings, filters and  
gates, can be substituted for or used in combination with  
30 doped fiber 46 to achieve desired characteristics in the  
20 switch 22.

The waveband selector 30 may include reflective ( $\geq 50\%$   
35 reflectance) and/or transmissive ( $\leq 50\%$  reflectance) selective  
elements that can be used to pass, either reflect or transmit,  
any of the wavebands 16 that comprise the signal 24. The  
25 waveband selector 30 may employ Mach-Zehnder filters, Fabry-  
Perot filters, and Bragg gratings to perform the waveband  
40 selection.

As shown in Figs. 6 and 7, waveband selectors 130 and  
230, respectively, can include a plurality of in-fiber  
45 30 reflective Bragg gratings 50 (Fig. 5) and/or transmissive  
Bragg gratings 52 (Fig. 6) to pass selected wavebands to the  
output ports 32. Each grating, 50 and 52, can be provided to  
pass selected wavebands to output ports 32. Alternatively,  
50 the waveband selector 30 may include a series of multiple

5 Bragg gratings that provide for piecewise coverage of the  
waveband. In the case of a multiple grating waveband  
10 selector, some separation of the wavelengths in the waveband  
will occur between gratings, but the multiple gratings are  
5 collectively operated to pass or substantially prevent the  
passage of the waveband. The multiple grating selector can  
be tuned to individual idler gaps or telescoped to one or  
15 more common idler gaps to decrease the idler gap bandwidth.

The number of gratings in Figs. 6 and 7 is shown as being  
10 equal to the number of wavebands 16 being switched. However,  
the number of selectors provided in the switch does not  
20 necessarily have to correspond to number of wavebands 16  
currently in the system. For example, the configurations  
shown in Figs. 5-11 may also be suitable for use in add/drop  
25 multiplexers, as well as demultiplexers or multiplexers, in  
which any number of wavebands can be processed.

It may also be advantageous to provide sub-wavebands  
within the wavebands 16 of varying size that can be received,  
30 divided into the sub-wavebands, and the sub-wavebands can  
20 further transmitted to other receivers within the system. The  
waveband selectors 30 can also be used to pass multiple  
wavebands to reduce the number of components in the system. 10.  
35 In addition, the wavebands 16 can be selected to overlap to  
allow one or more wavelengths 18 to be transmitted in multiple  
25 wavebands 16.

As shown in Fig. 6a, a waveband selector 130 can include  
40 a three port circulator 54 used in conjunction with the  
plurality of reflective Bragg gratings 50 using a  
configuration similar those discussed in U.S. Patent Nos.  
45 5,283,686 and 5,579,143 issued to Huber, and 5,608,825 issued  
30 to Ip. In Fig. 6b, a waveband selector 230 employs  
transmissive gratings 52 to transmit selected wavebands to the  
output ports 32 and reflect the remaining wavebands. An  
50 optical isolator 56 can be incorporated to prevent reflected

5 wavebands from propagating back to the input ports 28. One skilled in the art will appreciate that directional couplers and other directional devices can be substituted for the optical circulators with appropriate circuit modifications.

10 The optical processing node 20 may include a wavelength converter 58 to provide for switching one of more of the wavelengths in the transmitted signal 24. In Fig. 6a, the wavelength converter 58 is shown before the waveband selector 30; however, the wavelength converter 58 may also be positioned after the waveband selector 30 and operated accordingly.

20 Similarly in Fig. 7, a waveband selector 330 can be used with one or more directional devices, such as a circulator or a coupler, with either reflective or transmissive waveband gratings, 50<sub>i</sub> or 52<sub>i</sub>, to select wavebands. It will be appreciated that the selector 330 can be employed as an add and/or drop device/port, as well as a filter or in a demultiplexer or multiplexer in the system 10.

30 The optical distributor 34 associated with the input port 28 can be embodied as an optical splitter to split the signal 24 and distribute a portion of the entire signal 24 to each of the output ports 32. As shown in Fig. 8a, the optical distributor 34 can be embodied as a circulator 54 to provide the entire signal to each waveband selector 430. Wavelengths within waveband of the selector 230 are transmitted to the output port 32, while the remaining wavelengths are reflected by the transmissive gratings and circulated to successive ports.

40 Likewise, optical couplers can serve as the distributor 34 to provide the entire signal to waveband selector 530 (Fig. 8b). One skilled in the art will appreciate that directional devices, such as multiple three port circulators and/or coupler, can be cascaded in various other configurations equivalent to those shown in Figs. 8a&b. The gratings, 50 or

5 52, could be prepared having a reflectivity and transmittance of less than 100%, to allow a portion of signal to be transmitted and reflected.

10 The fiber Bragg gratings 50 and 52 used in the switch 22 can be permanently and/or transiently produced. Embodiments of the present invention incorporate fixed and/or tunable permanent Bragg gratings, 50 and 52 as the waveband selectors  
15 30. The permanent gratings used in the present invention can be prepared by conventional methods, such as by using  
10 ultraviolet (UV) light to irradiate a GeO<sub>2</sub> doped fiber core. Such methods are discussed in U.S. Patent Nos. 4,725,110  
20 issued to Glenn et al., 5,218,655 and 5,636,304 issued to Mizrahi et al., which are incorporated herein by reference, and related patents.

25 The permanent gratings can be tuned to provide for reflectance of a waveband in one mode and transmittance in another mode. Tuning of the grating properties can be accomplished mechanically (stretching), thermally, or  
30 optically, such as discussed in U.S. Patent Nos. 5,007,705, 5,159,601, and 5,579,143, and by M. Janos et al., Electronics Letters, v32, n3, pp. 245-6, electronically, or in some other appropriate manner.

35 A limitation of tunable permanent gratings is that a portion of the wavelength band can not be used to transfer  
25 signals. The unused portion of the wavelength band, called an "idler" gap, is necessary to provide each permanent grating  
40 with a gap in the wavelength spectrum in which the grating will not affect a signal encountering the grating.

Transient reflective or transmissive gratings, 50<sup>T</sup> and  
45 30 52<sup>T</sup>, respectively, could also be used in the waveband selector 30. Transient gratings can be used to reduce or eliminate the need for idler gaps in the transmission wavelengths and provide increased flexibility in the wavelength selectivity of  
50 the switch 22.



5 Transient gratings, either  $50^T$  or  $52^T$ , can be formed in  
a portion of the fiber in which the refractive index of the  
10 fiber can be transiently varied to produce a grating. In an  
embodiment, the fiber portion is doped with Erbium, other  
5 rare earth elements, such as Yb and Pr, and/or other dopants  
that can be used to vary the refractive index of the fiber to  
produce a grating. In another embodiment, the transient  
15 grating can be formed in a fiber section that contains a  
permanent grating to provide a combined performance grating  
and/or to establish a default grating in the absence of the  
20 transient grating.

As shown in Figs. 9-11, transient gratings can be written  
by introducing a grating writing beam either directly into the  
transmission fiber or by coupling the writing beam into the  
25 transmission fiber. One or more transient grating writing  
lasers  $60_i$  are used to introduce a transient grating writing  
beam into the doped portion of the signal waveguide 26. In a  
waveband selector 630 shown in Fig. 9, the writing beam is  
30 split into two paths and introduced into the transmission  
fiber 26 via ports 62. A plurality of narrow wavelength  
reflective gratings  $64_i$  are positioned in one of the writing  
beam paths to control the position of the standing wave in  
35 the waveguide 26 by introducing a time delay on the  
wavelengths of the writing beam. Narrow wavelength  
reflective or transmissive gratings,  $64_i$  or  $66_i$ , can also be  
25 used to remove the writing beam from the transmission fiber  
26.

As shown in Fig. 10, the writing beam can also be  
reflected back upon itself using spaced narrow wavelength  
45 reflective gratings  $64_i$ , to form a standing wave and produce  
a transient gratings  $50^T$  in waveband selector 730. The  
grating writing lasers  $60_i$  can be operated in conjunction  
with modulators 68 and pulsing switches 70 to control the  
50 coherence of the writing lasers  $60_i$  and the resulting

5 transient gratings 50<sup>T</sup>. A waveband selector 830, shown in  
Fig. 11, can also be configured with a reflector 72 in a  
coupled fiber to establish a standing wave by reflecting the  
10 writing beam back upon itself to form the standing wave in a  
5 manner similar to that described with respect to Fig. 10.

Single wavelength continuous writing beam arrangements  
have been used for signal identification and pattern  
15 recognition as discussed by Wey et al., "Fiber Devices for  
Signal Processing", 1997 Conference on Lasers and Electro-  
10 Optics, Baltimore, MD. Also, U.S. Patent No. 5,218,651  
issued to Faco et al., which is incorporated herein by  
20 reference, describes two beam methods for producing a  
transient Bragg grating in a fiber.

In systems 10 of the present invention, the switch 22  
15 can be used to optically connect a transmitter and a receiver  
(Fig. 1) in a 1x1 configuration or a plurality of nodes 100  
in an nxm configuration (Figs. 12-13). In a 1x1  
configuration, the switch 22 can be useful for dropping  
30 wavebands or for varying the waveband characteristics (gain  
trimming) of the signal.

The nodes 100 used in the system 10 may contain various  
system components including optical transmitters, receivers,  
35 and/or other processing equipment, such as switches depending  
upon whether the node is an origination (transmitting  
25 signals) and/or a destination (receiving signals) node, and  
whether it is a terminal node. The system 10 may further  
40 include other optical transmission equipment, such as optical  
amplifiers 74, and other optical processing nodes 20, such as  
optical add/drop multiplexers, between the switches and the  
30 nodes 100 as may be useful in a given system.

45 The 4x4 switch arrangement shown in Fig. 12 is  
representative of a north-south-east-west communication  
system. One skilled in the art will appreciate that the  
50 nodes/switch arrangements can be varied to accommodate

5 various network configurations. For example, a 3x3  
arrangement is shown in Fig. 13. The arrangements in Figs.  
12 and 13 show the cross connections of the switches 22, but  
10 do not show the waveband selectors within the switches 22.

5 The flow of communication traffic between the nodes can  
take place using a variety of optical waveband hierarchies.  
In an embodiment, the optical wavebands are established and  
15 wavelengths assigned based on both the signal origination  
node and the signal destination node to avoid the need for  
20 wavelength conversion in the optical network.

For example, the spectrum of wavelengths used with each  
20 receiver can be divided into wavebands and the destination  
wavebands assigned to transmitters. The assignment may be  
static or dynamically controlled at the network management  
25 level so no overlap occurs in the wavebands assigned to each  
transmitter from the various receivers. Dynamic control of  
the waveband assignment provides flexibility in the  
wavelength management in the system 10 and can be performed  
30 at various points in the system, such as at the client  
20 system, e.g., SONET, SDH, ATM, IP interface with the optical  
network.

Waveband hierarchies in which the origination and  
35 destination nodes are paired are particularly useful in  
communication systems in which a signal is being sent from  
25 the origin to one destination, such as in telephone  
communication systems. In addition, the present invention  
40 can also accommodate the necessary protection systems to  
provide multiple paths to the same destination by proper  
allocation of the wavelengths.

45 30 In a multiple destination system, such as a cable  
television system, it may be more appropriate for the  
wavebands to be determined based solely on the origination  
node of the signal. Waveband selectors can be included in  
50 the switches 22 to pass signals corresponding to a particular

5 source to any number of destination nodes. The switch 22 can  
provide further control over the distribution of signals by  
passing broadcast signals to a distribution segment only upon  
10 a subscriber's request. The CATV provider, in response to a  
5 programming request, can centrally control the switch to  
deliver the signal to the requester. In the absence of an  
express request by a subscriber the signal would not be  
15 broadcast to the segment. The limited availability of the  
signal on a segment may discourage pirating of programming  
10 signals.

20 Switches 22 of the present invention can also be used  
for remote switching and routing of communication traffic in  
the event of a fault in the system. For example, in Fig. 12  
if a signal were to travel from node A to node C, the typical  
25 path would be through the switch connected between nodes A  
and C. However, if a fault occurs in the line from the  
switch to node C, it may be desirable to route traffic from  
node A through node D to node C. Upon detection of the  
30 fault, the network management system could reconfigure the  
20 switches 22 in the system 10 to reroute the traffic or switch  
to a previously configured protection route.

35 As can be seen, the present invention provides for  
flexibility in optical transmission systems. In addition,  
the present invention provides for increased transmission  
25 capacity without the commensurate increase in complexity that  
was present in the prior art systems.

40 Those of ordinary skill in the art will appreciate that  
numerous modifications and variations that can be made to  
specific aspects of the present invention without departing  
45 from the scope of the present invention. It is intended that  
30 the foregoing specification and the following claims cover  
such modifications and variations.

Claims

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## CLAIMS

What is claimed is:

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1. An optical transmission system comprising:  
at least one optical transmitter configured to transmit  
5 information via at least one information carrying wavelength;  
at least one optical receiver configured to receive the  
information transmitted via the at least one information  
15 carrying wavelength; and,

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- at least one optical processing node including at least  
10 one waveband selector configurable to selectively pass and  
substantially prevent the passage of at least one optical  
20 waveband comprised of a plurality of information carrying  
wavelengths from at least one of said at least one  
transmitters to at least one of said at least one receivers.

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- 15 2. The optical transmission system of claim 1, wherein  
said at least one waveband selector is configured to  
selectively pass and substantially prevent the passage of  
30 said at least one optical waveband without separating said  
plurality of information carrying wavelengths into individual  
20 information carrying wavelengths.

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3. The optical transmission system of claim 1, wherein  
35 each of said at least one waveband selectors is configured to  
only selectively pass and substantially prevent the passage  
of optical wavebands.

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- 25 4. The optical transmission system of claim 1, wherein  
said at least one optical processing node includes an optical  
switch having input ports corresponding to said at least one  
45 transmitter and output ports corresponding to said at least  
one receiver and said information carrying wavelengths are  
30 switched from said input ports to said output ports in said  
at least one optical waveband by said at least one waveband  
50 selector.

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5. The optical transmission system of claim 4 wherein said switch includes

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a waveband demultiplexer corresponding to each input port and configured to receive and separate an optical signal containing the at least one information carrying wavelength into separate optical wavebands signals,

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an optical splitter in optical communication with and corresponding to each of the separated waveband signals from each of said optical demultiplexers, each of said optical

10 splitters configured to split the separated waveband signals into a number of split waveband signals corresponding to each output port,

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at least one said waveband selectors being positioned to receive each split waveband signal and configurable to pass

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15 and to substantially prevent the passage of the split waveband signal to said corresponding output port, and

an optical combiner corresponding to each output port and configured to receive the split waveband signals from each of said waveband selectors corresponding to said output port and provide a combined optical waveband signal to said output port.

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6. The optical transmission system of claim 5 wherein at least one said waveband selectors includes a doped optical fiber configured to allow an optical waveband to pass through the fiber in one mode and to substantially prevent the passage of the optical waveband through the fiber in another mode.

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5           7. The optical transmission system of claim 6 wherein  
doped optical fiber includes an erbium doped fiber coupled to  
an optical energy pump source, the erbium fiber being  
10       configured to substantially prevent the passage of the  
5       optical waveband signal when said fiber is not pumped with  
optical energy from said optical energy pump source and to  
allow said optical waveband signal to substantially pass  
15       through the fiber when pumped with optical energy from said  
pump source.

10           8. The optical transmission system of claim 7 wherein  
20       said optical energy pump source is configured to control the  
intensity of the optical waveband passing through the fiber  
by varying the optical energy pumped into the erbium doped  
fiber.

25           9. The optical transmission system of claim 5 wherein  
at least one of said waveband selectors is selected from the  
group consisting of doped fiber, mechanical, electro-optic,  
30       liquid crystal switches, semiconductor, and combinations  
thereof, in which said switch can be operated to pass at  
20       least one waveband in one mode and substantially prevent the  
passage of said at least one waveband in another mode.

35           10. The optical transmission system of claim 1, wherein  
said at least one optical processing node includes an optical  
add/drop device containing said at least one waveband  
40       25       selector to selectively add an optical waveband to be  
transmitted to said at least one receiver and to selectively  
drop an optical waveband transmitted by said at least one  
45       transmitter.



5           11. The optical transmission system of claim 1, wherein  
said at least one optical processing node includes ports  
selected from the group consisting of add devices, drop  
10 devices and combinations thereof.

5           12. The optical transmission system of claim 1, wherein  
said at least one optical processing node includes a  
demultiplexer configured to receive the information carrying  
15 wavelengths from said at least one transmitter and distribute  
the information carrying wavelengths in optical wavebands to  
10 at least one of said at least one receivers.

20           13. The optical transmission system of claim 1, wherein  
said at least one optical processing node includes a  
multiplexer configured to receive optical wavebands passed by  
25 said at least one waveband selector and provide a multiple  
15 optical waveband signal to said at least one receiver.

30           14. The optical transmission system of claim 1 wherein  
said at least one waveband selector includes transmissive and  
reflective waveband selectors selected from the group  
consisting of optical filters, Bragg gratings, gates,  
20 switches and combinations thereof.

35           15. The optical transmission system of claim 1 wherein  
said at least one waveband selector includes an optical  
waveguide configured to provide for the formation of an  
40 optical grating therein.

45           16. The optical transmission system of claim 1 wherein  
said at least one waveband selector includes a permanent  
Bragg grating selected from the group consisting of  
transmissive and reflective operated permanent gratings.

50           17. The optical transmission system of claim 1 wherein  
said at least one waveband selector includes a tunable  
grating.

5           18. The optical transmission system of claim 17 wherein  
said tunable grating is selected from the group consisting of  
mechanically, thermally, optically, and electronically  
10       tunable gratings, and combinations thereof.

5           19. The optical transmission system of claim 1 wherein  
said at least one waveband selector includes an optical  
15       circulator having a first port optically connected to said at  
least one transmitter, a second port optically connected  
between said first port and a reflective grating configured  
20       to reflect said at least one waveband and a third port  
optically connected to pass a reflected waveband from said  
reflective grating to said at least one receiver.

25           20. The optical transmission system of claim 1 wherein  
said at least one waveband selector includes an optical  
15       circulator having a first port optically connected to said at  
least one transmitter, a second port optically connected to  
said first port and a transmissive grating configured to  
30       transmit said at least one waveband from said second port to  
said at least one receiver.

20           21. The optical transmission system of claim 1 wherein:  
35       said at least one optical receiver includes a plurality  
of optical receivers;  
said at least one optical transmitter includes a  
plurality of optical transmitters; and,

40       25       said optical processing node includes a switch optically  
connecting said transmitters and said receivers and  
configured to pass optical wavebands of information from said  
transmitters to said receivers.

45           22. The optical transmission system of claim 1 wherein  
30       said optical processing node is configurable to provide any  
of one or more wavebands from any of said at least one  
50       transmitters to any of said at least one receivers.

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23. The optical transmission system of claim 1, further comprising:

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a demultiplexer corresponding to each of said at least one transmitters and configured to receive and separate the plurality of individual information carrying wavelength signals; and,

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a plurality of wavelength converters optically connecting said demultiplexer and said at least one waveband selector and configured to convert the plurality of information carrying wavelength signals from said demultiplexer into information carrying wavelengths within said at least one waveband.

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24. The optical transmission system of claim 1 wherein said at least one transmitter includes at least one modulated laser for providing at least one of said information carrying wavelengths and said receiver includes a plurality of photodiodes corresponding to said plurality of information carrying wavelengths in said at least one optical waveband.

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25. The optical transmission system of claim 1 wherein said at least one waveband selector comprises an in fiber Bragg grating configured to selectively pass said optical waveband including said plurality of information carrying wavelengths.

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26. A method of passing information to a destination comprising:

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producing an optical signal comprised of a plurality of information carrying wavelengths;

transmitting the optical signal; and,

passing only a selected optical waveband of the optical signal including more than one of the plurality of information carrying wavelengths to a destination without separating the individual information carrying wavelengths.

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27. The method of claim 26 further comprising  
separating the information carrying wavelengths from the  
waveband at the destination into individual information  
carrying optical wavelengths; and,  
5 reproducing the information contained in the information  
carrying wavelengths in electronic form.

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28. The method of claim 27 wherein said passing  
includes providing a Bragg grating to selectively reflect or  
transmit the optical waveband of information to the  
10 destination.

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29. A method of passing information from an origin to a  
destination comprising:

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assigning a waveband comprised of a band of wavelengths  
to at least one destination;

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providing an optical processing node containing a  
waveband selector configured to pass the waveband of  
information to the at least one destination without  
30 separating the individual information carrying wavelengths in  
the waveband;

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producing an optical signal including a plurality of  
information carrying wavelengths within the assigned  
35 waveband;

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transmitting the optical signal to the optical  
processing node; and,

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passing the optical signal through waveband selector in  
the optical processing node to selectively pass the assigned  
waveband of information to the at least one destination  
45 without separating the individual wavelengths.

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30. The method of claim 29 wherein said passing  
30 includes providing a pumped erbium doped fiber in the  
waveband selector to selectively pass assigned wavebands to  
the at least one destination.

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31. The method of claim 29 wherein said passing includes providing at least one grating selected from the group consisting of reflective and transmissive gratings and combinations thereof in the waveband selector to selectively pass assigned wavebands to the at least one destination.

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32. An optical switch comprising:

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at least one input port;

at least one output port; and,

at least one waveband selector providing optical .

10 communication between said at least one input port and said at least one output port, wherein said at least one waveband selector is configurable to pass or substantially prevent the passage of information in at least one optical waveband between said at least one input port and said at least one output port, and at least one of said at least one optical wavebands includes a plurality of information carrying wavelengths.

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33. The method of claim 32 wherein said at least one waveband selector is configured to information carrying wavelengths only as a part of said at least one optical waveband.

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Fig. 1

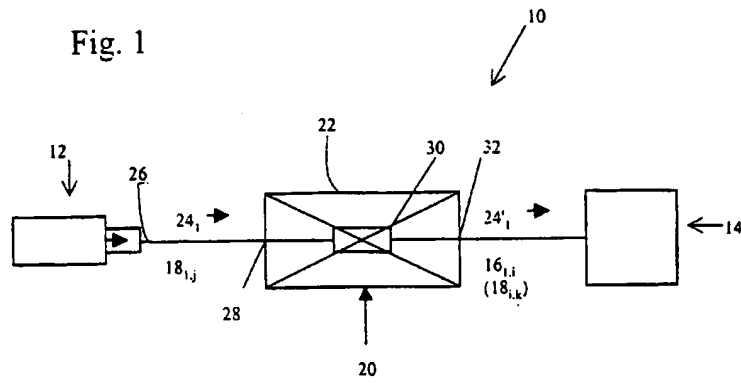
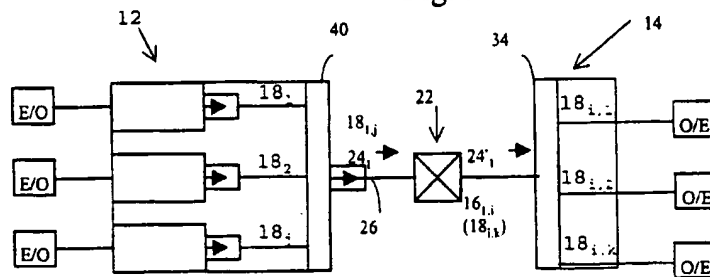


Fig. 3



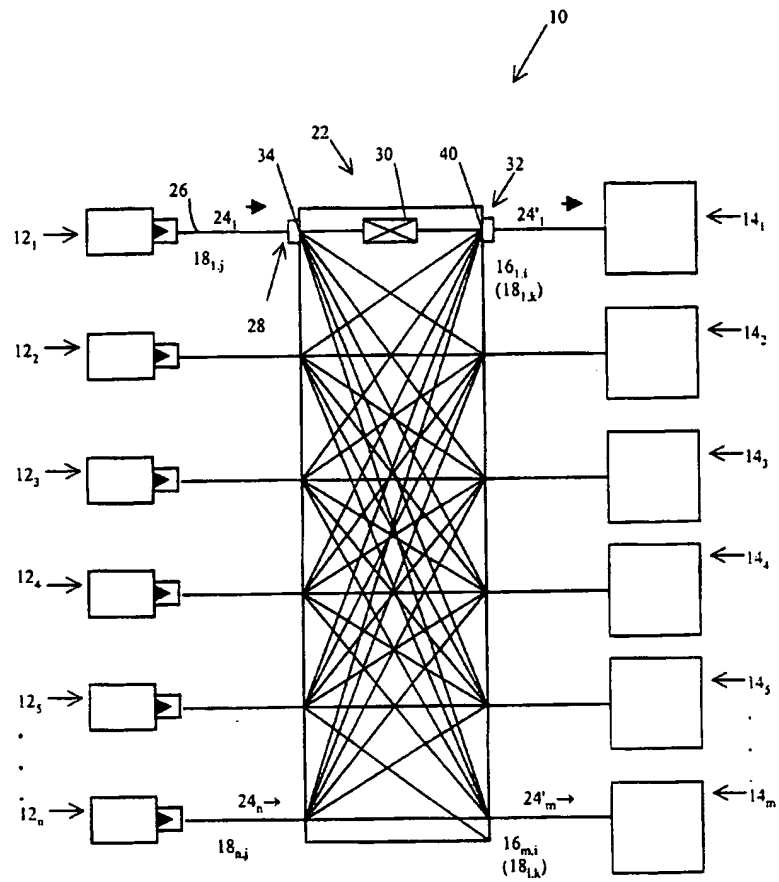


Fig. 2

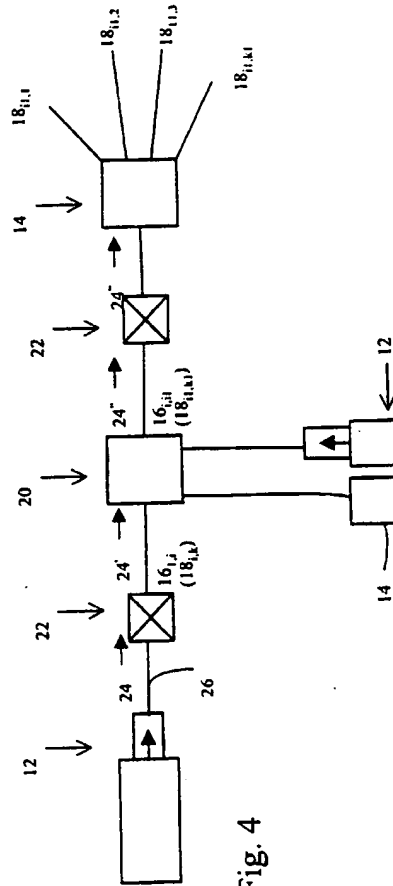
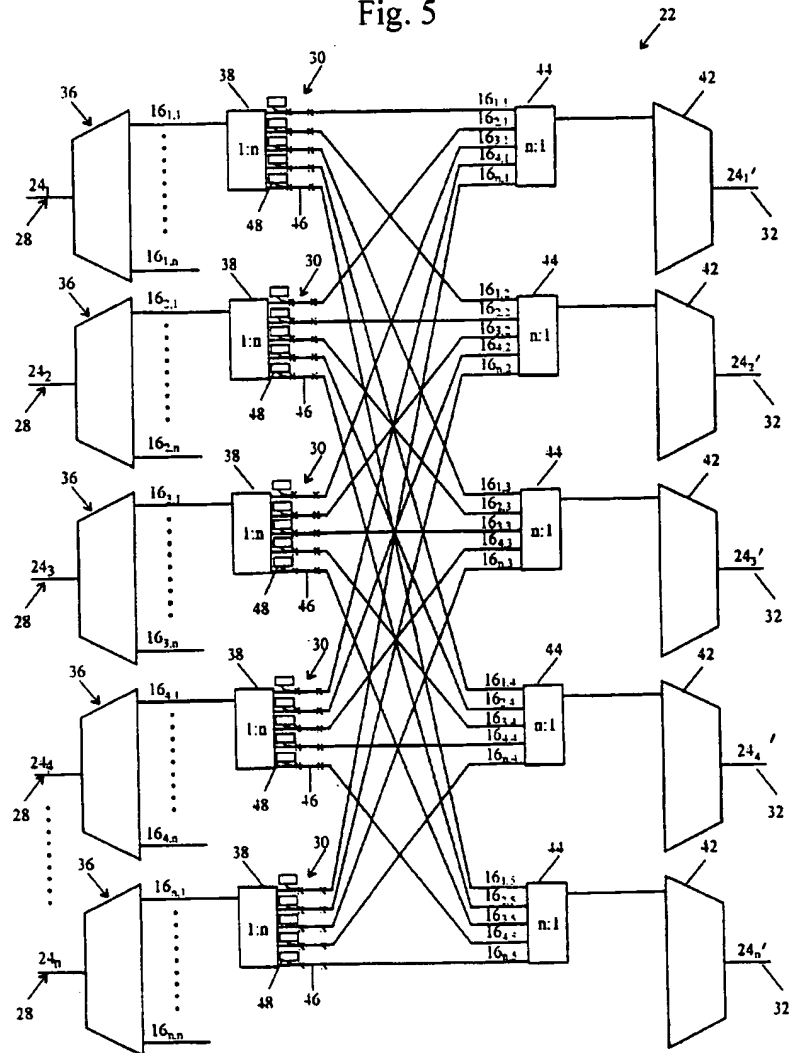
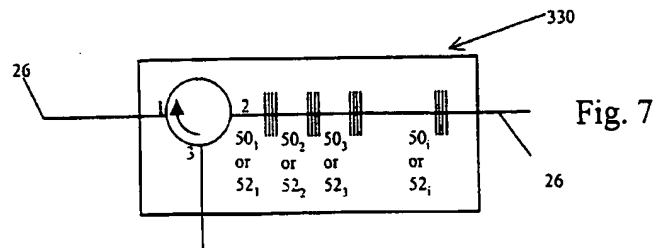
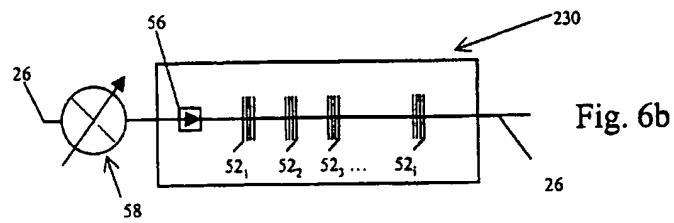
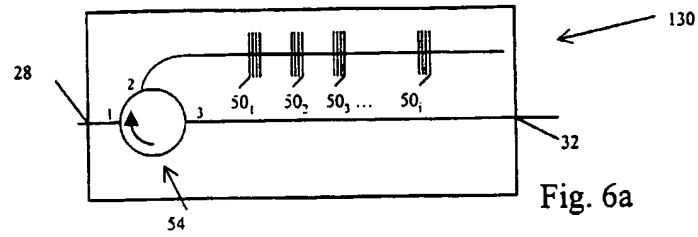


Fig. 4



Fig. 5





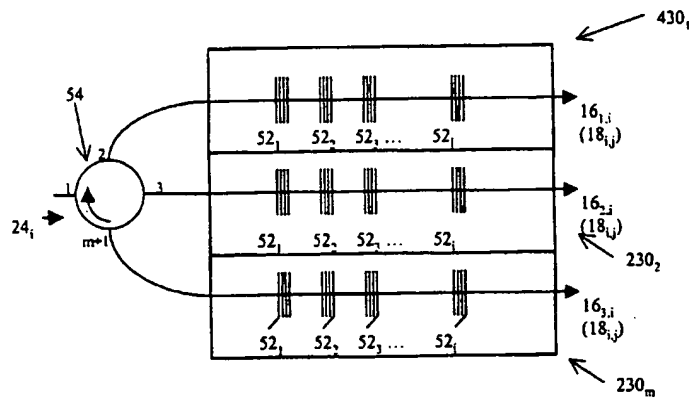


Fig. 8a

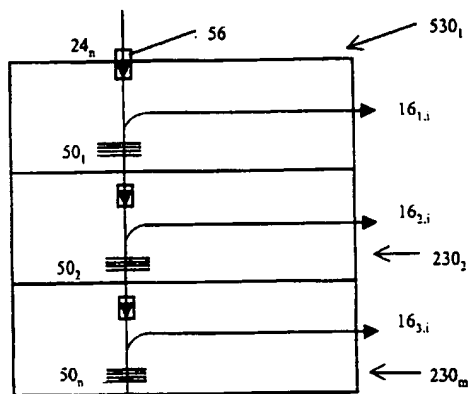


Fig. 8b

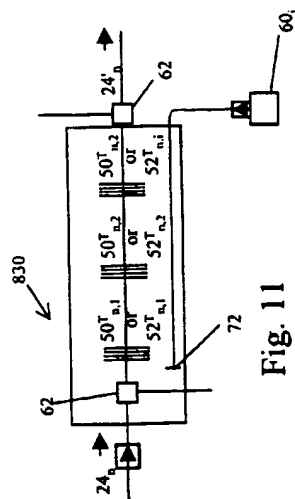
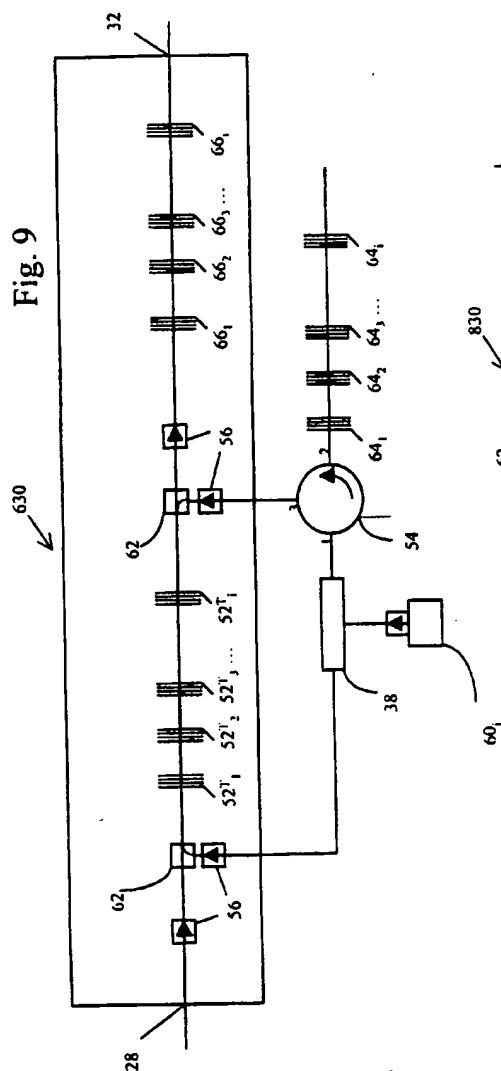
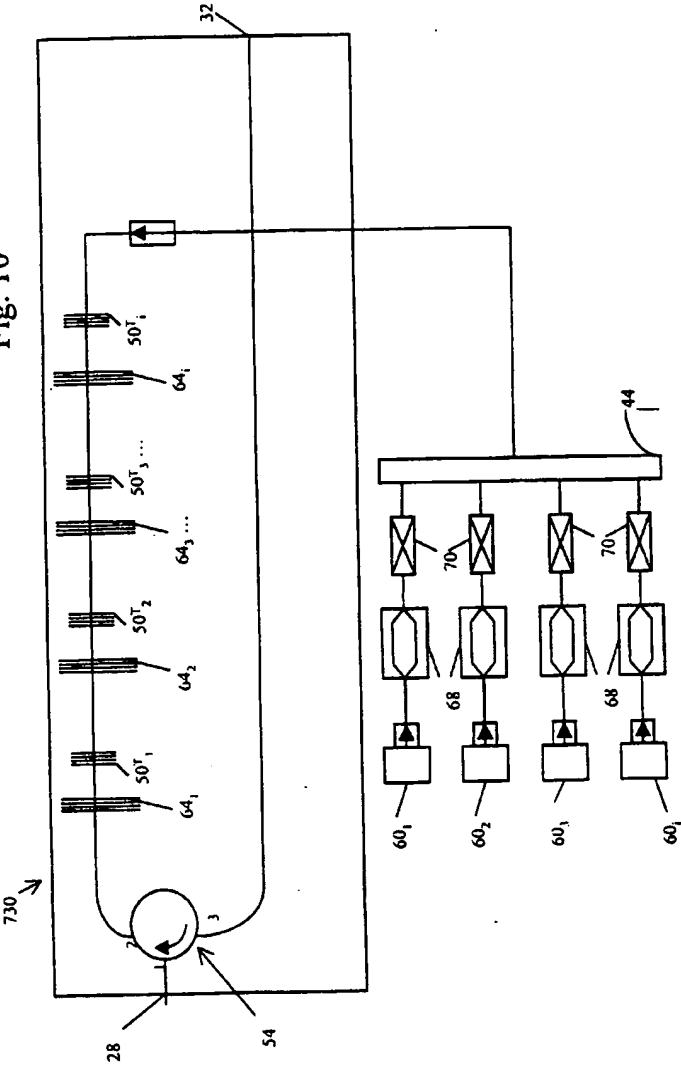


Fig. 10



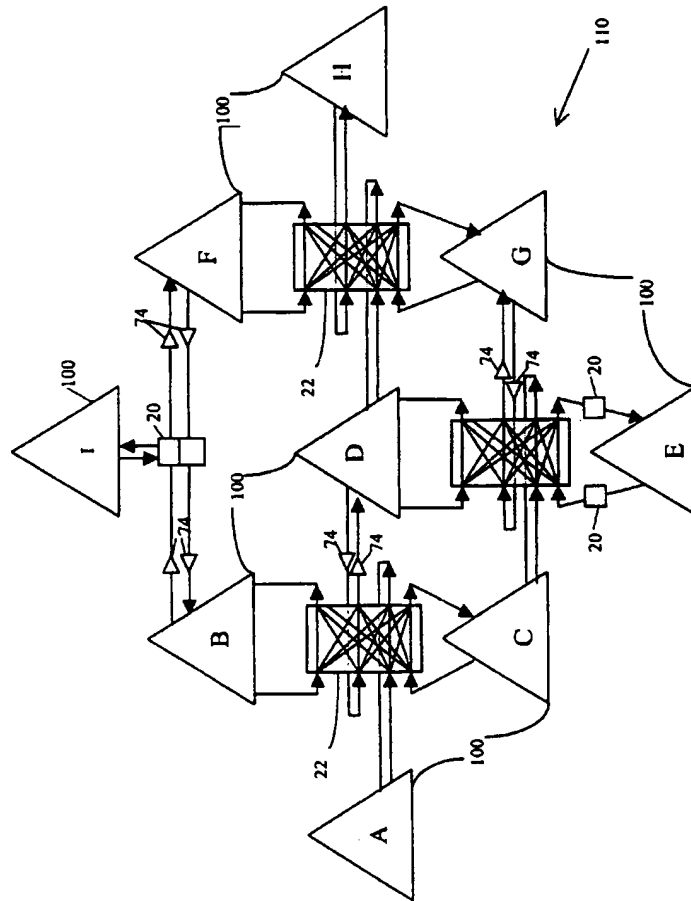


Fig. 12

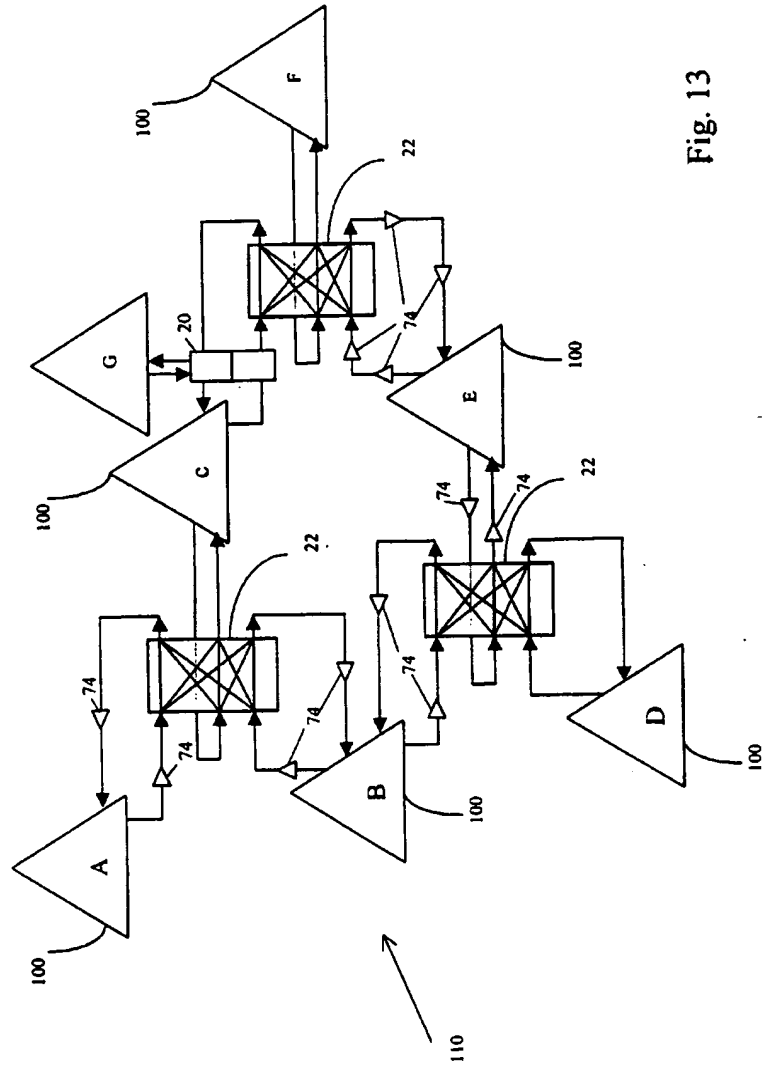


Fig. 13

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US99/16485

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : H04J 14/02, 14/00, H04B 10/00

US CL : 359/117, 125, 127, 128, 130, 134, 160

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 359/117, 125, 127, 128, 130, 134, 160

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of documents, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	WO 95/13687 A (MCGUIRE et al.) 18 MAY 1995, see pages 8-15 and figs. 2-8	1, 3-5; 12-14, 21-24, 32 — 2, 6-11, 15-20, 25, 28, 30, 31, 33
X — Y	US 5,652,814 A (PAN et al.) 29 July 1997, see col. 1, lines 10-14, col. 15, lines 1-2, 16-18, col. 16, lines 27-28, 51-67, col. 17, lines 1-10 and 212, 213, 214, 218 in figs. 19, 20 and 261, 262 in fig. 22 and 271, 272, 273 in fig. 25	26, 27, 29 — 2, 28, 30, 31, 33
Y	US 5,623,362 A (MITSUDA et al.) 22 April 1997, col. 7, lines 35-50, col. 11, lines 8-25 and 101, 102, 103, 107 in fig. 1	6-9, 30

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
*A* document defining the general state of the art which is not considered to be of particular relevance	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
*B* earlier document published on or after the international filing date	*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
*L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*A* document member of the same patent family
*O* document referring to an oral disclosure, use, exhibition or other means	
*P* document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

18 SEPTEMBER 1999

Date of mailing of the international search report

27 OCT 1999

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## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US99/16485

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of documents, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,706,375 A (MIHAILOV et al.) 06 January 1998, col. 1, lines 10-22, 40-50, col. 7, lines 54-56, 65-67 and fig. 1 and 74 in fig. 7	15-18, 25
Y	US 5,771,112 A (HAMEL et al.) 23 June 1998, col. 4, lines 17-20, col. 8, lines 2-3 and M1, M2 in fig. 1	10-11
Y	US 5,742,416 A (MIZRAHI) 21 April 1998, col. 10, lines 19-2-, 32-35, 41-46, 52-59, 66-67, col. 11, lines 1-2, 24 and 172, 175, 188 in fig. 4	19
Y	US 5,712,932 A (ALEXANDER et al.) 27 January 1998, col. 6, lines 45-61, col. 8, lines 38-43 and 20, 70, 72, 76, 80 in fig. 1A	20